Copper

HEAVY METAL INDEX · REFERENCE

November 2026

Karen Pendergrass · Heavy Metal Index, Institute of Contaminant Standards

CITE AS

Pendergrass, K. (2026). Copper. Heavy Metal Index. https://heavymetalindex.com/metals/copper

CORRESPONDENCE

Corrections are logged publicly on the article page, each with its date, the affected value, and the source that resolved it.

KEYWORDS

heavy metals, food safety, dietary exposure

PUBLICATION HISTORY

This revision 2026-11-03.

Abstract

An essential enzyme constituent, copper requires separate interpretation in excess exposure and inherited metabolism disorders.

This page draws on 27 peer-reviewed studies and 3 other cited sources. The complete citation list is at the bottom of the page.

1 | Overview

Copper is an essential metal in enzymes including cytochrome c oxidase, lysyl oxidase, and copper/zinc superoxide dismutase, but excess copper can produce gastrointestinal and hepatic toxicity 1. It also frames inherited copper-metabolism disorders including Menkes disease and Wilson disease 1.

The evidence on this page falls into three groups. The first is copper in the human body: liver and kidney from autopsies, plasma, serum, whole blood and brain tissue 2 3 4. The second is copper in foods and in the animals and environments that produce them, including cattle liver, grape must, vegetables, soils and irrigation water 5 6. The third is toxicology, where an animal model of Wilson's disease shows how failed copper excretion turns a normal copper diet into liver failure 7.

2 | Toxicology

Excess copper and the liver

Excess copper can produce gastrointestinal and hepatic toxicity 1. In Long Evans Cinnamon rats, which lack working ATP7B copper transport as people with Wilson's disease do, every one of 15 rats fed a normal diet containing 13 ppm copper developed acute liver failure, at a median age of 13 weeks, and mortality in that group reached 40% by the end of the 28-week study 7. None of 9 rats of the same strain fed a diet with less than 1 ppm copper developed liver failure or died over the same period 7. The model shows that the harm depends on the combination of impaired copper excretion and ordinary dietary copper, not on an unusual copper source.

Food-producing animals show the same liver-centered pattern. A survey of UK cull cattle describes copper loading, the accumulation of copper in the liver, as often the precursor of chronic copper toxicity, a syndrome of liver necrosis followed by a hemolytic crisis 5. The authors note that some apparently healthy cull cattle carried liver copper above concentrations reported in cattle that had died of copper toxicity, so a high liver value raises risk without guaranteeing disease 5.

Copper status in chronic disease

Several human studies report altered copper in disease, but in different directions and without any measure of intake. Plasma copper was higher in Algerian patients with papillary thyroid carcinoma than in controls, and the authors propose the copper-to-zinc ratio and copper isotope ratio as diagnostic markers rather than as evidence of copper exposure 3. Serum copper did not differ between Turkish adults with euthyroid nodular goiter and healthy controls 8. Brain copper was lower, not higher, in seven of nine brain regions in Parkinson's disease dementia, and the authors report similar decreases in four regions in their earlier Alzheimer's disease dementia work 4. A conference abstract from New Delhi found blood copper somewhat higher in people with Alzheimer's disease, but the difference was not statistically significant 9.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
5 Tlemcen and Oran, Algeria	Plasma; thyroid cancer case-control	Total Cu	1346.1 ± 328.3 µg/L in patients vs 1060.5 ± 216.1 µg/L in controls (mean ± SD)	46 / 50	Higher in patients ($p < 0.0001$); disease marker, not exposure
6 Yozgat, Turkey	Serum; nodular goiter cross-sectional	Total Cu	1293.75 ± 249.33 µg/L in patients vs 1306.56 ± 258.53 µg/L in controls (mean ± SD)	98 / 83	No difference ($p = 0.833$); single clinic
7 UK tissue bank	Post-mortem hippocampus; Parkinson's disease dementia	Total Cu	177.4 vs 303.1 µmol/kg dry weight (means)	9 / 27	Lower in dementia ($p = 0.0010$); small groups, pooled controls
7 UK tissue bank	Post-mortem substantia nigra; Parkinson's disease dementia	Total Cu	201.8 vs 306.8 µmol/kg dry weight (means)	9 / 9	Lower in dementia ($p = 0.003$)
8 New Delhi, India	Blood; Alzheimer's disease case-control (abstract)	Total Cu	1401 ± 128.4 µg/L vs 1206 ± 67.25 µg/L (dispersion statistic not named)	25 / 20	Not significant ($p = 0.2251$); blood fraction not stated

Non-human toxicity context

This review synthesizes oxidative-stress and physiological responses to pesticides and heavy metals in stingless bees. Its copper-sulfate evidence concerns laboratory bee exposure and pollinator health; it supplies no honey concentration or human exposure measurement. Supports pollinator ecotoxicology and metal/pesticide stress-pathway context. Reported copper effects include mortality, locomotion, midgut damage and oxidative/apoptotic responses; do not extrapolate these endpoints to human health or honey contamination 10.

3 | Typical exposure routes

Diet and excretion

In a 1970s Tokyo study, copper and zinc were the most closely correlated pair of metals in both hospital-diet composites and feces, and the authors found that the relationships among copper, zinc, lead and cadmium in food and feces were similar to each other but very different from those in liver and renal cortex 2. Daily fecal copper excretion averaged 1.32 ± 0.91 mg/day in 19 Tokyo men aged 21 to 24, 1.27 ± 0.73 mg/day in 30 men over 50 from a control area, and 2.71 ± 1.82 mg/day in 30 men over 50 from a cadmium-polluted area 2. The paper did not report the copper concentration of the diet itself, so these figures describe excretion, not intake.

Animal feed and food-animal tissue

In the Texas feed survey, a poultry vitamin/mineral concentrate contained 1,170 mg/kg copper and a goat feed contained 115 mg/kg (Results 3.3). The authors identified added copper sulfate in both. Nutrient concentrates and finished rations require separate interpretation; the observations alone do not establish a manufacturing contaminant fraction or human exposure 11.

Feed supplementation is the main copper route for housed cattle. Across 510 UK cull cattle, liver copper showed no relationship with underlying topsoil copper, which the authors expected because most dairy cattle eat purchased feeds and supplements 5. The same paper cites a survey of 50 dairy farms in which mean total copper intake was 27.9 mg/kg dry matter, with a range of 12.9 to 57.9 mg/kg dry matter 5.

Soil, water and food-chain transfer

One Nilore, Islamabad soil characterization reported copper of 1.30 µg/g by bulk elemental analysis (Table 2). The source does not state a wet/dry basis or replicated uncertainty. This is a local soil result; it does not measure food occurrence or crop transfer 12.

Road-zone soils near Arzew had copper mean 31.95 mg/kg, median 21.53 mg/kg and maximum 223.7 mg/kg (N=27). The spatial map uses a copper scale ending at 81 mg/kg, so its plotted surface cannot be substituted for the measured table extrema. Concentrations refer to air-dried aqua-regia-extracted soil (Table 2; Figure 3) 13.

In the Banat soil-nettle-snail study, Table 1 gives a soil-copper versus foot-copper correlation of 0.45, labelled nonsignificant, despite a contrary narrative claim. Nettle copper versus foot copper is 0.90 ($P<0.01$). Figure 1 also shows foot copper exceeding hepatopancreas copper at two sites, so the hepatopancreas is not uniformly the more concentrated tissue. These are wild sentinel tissues on a dry basis, with dilute-acid-extractable soil as the environmental comparator 14.

The Ganga survey reports river-water copper means of 1.35, 2.54, 2.54 and 4.58 mg/L at Kanpur, Allahabad, Mirzapur and Varanasi respectively (Table 3). Separate fish-muscle summaries have a wet/dry-basis conflict,

and the source’s tissue/water indices and dietary-risk calculations are not sufficiently consistent to validate e xposure conclusions 15.

4 | Food sources

Mixed diets

Daily composites of three hospital meals, including tea and milk, were analyzed for copper over 20 days in Tokyo, but the paper reports only correlations from these mixed meals, not their copper concentrations 2. The cited evidence therefore does not supply a dietary copper intake estimate for any population.

Organ meats

Liver is the organ where copper concentrates, in people and in cattle. In Tokyo autopsy cases, liver copper was several times higher than renal-cortex copper in every age group 2. In UK cull cattle, 52.2% of 510 livers were above the laboratory's normal range and 34.7% were above the reference range upper limit of 8000 µmol/kg dry matter, with dairy breeds more affected than beef breeds 5. These are animals at slaughter rather than retail organ meats, and the paper reports categories rather than mean concentrations, so it shows that beef and dairy cattle livers can carry high copper without giving a market distribution 5.

Grape must and wine

Copper in 18 French production grape musts ranged from 0.41 to 6.08 ppm by flame atomic absorption 6. The authors attribute raised copper in winemaking to metal tanks and pipes and to antifungal treatments in the vineyard, and they explain that wineries monitor copper because it causes reddish-brown "cupric crack" sediments, especially in white wine 6. Must is an intermediate, not the finished product, and the study did not measure wine.

STUDY / LOCATION	MATERIAL / DESIGN	METAL SPECIES	VALUE (UNITS AND BASIS)	N	INTERPRETATION / LIMITATION
3 UK abattoir, October 2012	Cull-cattle liver; abattoir survey	Total Cu	177 of 510 (34.7%) above 8000 µmol/kg dry matter; Holstein-Friesian 38.3%, beef cows 16.9%	510	Category counts only; cull animals, not retail liver
9 French wineries, 2021	Grape must; method comparison	Total Cu	0.41 to 6.08 ppm by flame atomic absorption (basis not stated)	18	Production intermediate, not wine; one laboratory's clients
2 Tokyo autopsies	Human liver; age-stratified	Total Cu	Geometric means 5.51 to 15.21 µg/g, wet basis per figure axes	85	Human organ reference, not food; 1970s methods

Crops grown with contaminated soil or irrigation water

The Nahavand farm study reported copper in farm soil, mixed-source irrigation water and whole above-ground crop biomass. Its cancer-risk chart assigns copper prominent values despite the absence of a copper cancer slope factor in its own input table. These model outputs are retained as source-error context, without a clinical-risk inference (Table 7; Figure 9) 16.

An Iraqi irrigation experiment measured lead, cadmium, iron and copper in dried edible broccoli and cauliflower heads grown under three irrigation regimes in Sulaymaniyah, Iraq. The tables preserve crop-specific differences: wastewater-irrigated broccoli had the largest listed values for the four metals, whereas cauliflower cadmium was greatest under alternating irrigation. The paired treatment summaries contribute source-native vegetable occurrence and irrigation-pathway evidence. The dried basis is not interchangeable with fresh vegetables. The experiment is site- and season-specific and does not characterize all river water, all Iraqi produce or long-term dietary exposure 17.

One study measured seven metals in sewage water, soil, spinach and cauliflower at two peri-urban sites in Faisalabad, Pakistan. The paper reports substantial differences between the two crop/site combinations, but its design does not separate plant-species effects from location. Concentrations are retained with the source's m easurement and tissue limitations. These are localized paired environmental and crop measurements, with plant r esults routed as leafy-tissue evidence. They do not establish a cauliflower-head concentration, a fresh-weight c oncentration, or a causal reduction in biomass from metal exposure. Industrial source attribution is proposed b y the authors, rather than measured by a source-apportionment experiment 18.

Another study measured seven metals in kenaf, chili pepper, tomato and spinach plant parts, with associated soil and irrigation water from Gobbiya Dam in Nigeria. The paper separates edible leaves or fruits from roots and stems. Its concentration tables are preserved independently of several inconsistent safety comparisons and a soil-index calculation that uses water standards. The organ-resolved dry-weight values support local occurrence and irrigation-pathway analysis. Roots, stems and non-edible leaves are retained as pathway context rather than assigned to edible-product distributions. Broad leafy-vegetable and herb/spice ingredient routes retain kenaf and chili identity in the structured record without substituting a named cultivar 19.

Premna latifolia leaves collected in three Andhra Pradesh villages had different reported elemental concentrations. Village-specific values are preserved as local leafy-vegetable evidence; the paper supplies no replicate counts or uncertainty estimates. Supports geographic variation in six elements in a specific wild edible leaf. It does not establish nutritional adequacy, safety, or a regional market distribution. The source's c haracterization of aluminium as an essential nutrient is not adopted 20.

This Sri Lankan study compares elemental concentrations and simulated digestive release in two leafy vegetables across five growing areas. Raw, coconut-milk-cooked and coconut-oil-stir-fried portions were tested separately; lower in-vitro release does not establish lower human absorption or safe consumption. Supports region-specific leafy-vegetable occurrence and cooking/bioaccessibility comparisons. Processing effects are not uniform: for example Wellampitiya A. sessilis gastric lead is 15.3% raw and 20.7% cooked. Coconut additions can change the matrix; an in-vitro endpoint is not in-vivo absorption 21.

Celery roots and garden soils from 26 households in a historically polluted Romanian area showed wide cadmium and lead variation in 2021 to 2022. Soil results use dry weight, while edible celeriac results use fresh weight; these paired measurements preserve a legacy-contamination pathway without assigning sole liability to any facility. Supports historical industrial-burden and present edible-root occurrence evidence. Celery here is

celeriac, not stalk celery; the product category is root/tuber vegetables. Geographic sampling is targeted to a polluted area and is not a national market sample 22.

A principal-component study analyzes metal contamination patterns across two historic Romanian mining areas and a reference area. The PCA study reproduces vegetable concentrations and male hazard quotients from an earlier 2011 study; these remain linked secondary observations rather than additional independent samples. Supports legacy mining and tissue/region differences. Parsley root and leaf remain distinct, as do carrot root and leaf. The fresh-matter food table is retained with cohort linkage so that a reanalysis cannot inflate the evidence pool. Source THQ rankings are model results, not clinical outcomes 23.

Botanical raw materials

One study compares nine elements in medicinal plant materials collected in disturbed and control environments in Russia's Voronezh region during 2015 to 2020. The reported ranges preserve tissue and environmental setting; t he paper also proposes regional background means across species. Supports geographic and tissue-specific c ontamination evidence for botanical raw materials and environmental attribution hypotheses. It does not measure f inished supplements or isolate an individual polluter's causal contribution 24.

Processed foods

Two anonymous chocolate products from Bwari market contained measurable nickel, iron, copper, chromium and lead. Their reported sample concentrations are preserved independently of inconsistent dispersion, intake means and safety comparisons in the paper. Provides a small local occurrence observation with anonymous products. It cannot establish market prevalence, source attribution, or a no-risk conclusion. Total chromium is not chromium(VI) 25.

5 | Regulatory limits

The cited evidence does not establish a human food, supplement or drinking-water limit for copper. The values below come from the papers cited and are mostly animal-feed, veterinary or clinical reference points rather than human food standards.

- **Cattle feed.** The UK cattle-liver paper states that the maximum dietary copper permitted without veterinary prescription under domestic and EU legislation is 35 mg/kg at 88% dry matter, which equates to 40 mg/kg of total diet dry matter, and that national guidance recommends total dietary copper of 20 mg/kg dry matter including supplements 5.
- **Cattle liver reference range.** The same paper uses an upper reference limit of 8000 µmol/kg dry matter for liver copper, and a laboratory "normal" range of 1405 to 5618 µmol/kg dry matter 5.
- **Human plasma reference range.** The thyroid cancer study classifies plasma copper against a reference range of 804 to 1,620 µg/L taken from a German population 3.
- **Wine processing.** The grape-must paper states that bentonite or gum arabic treatments used to prevent cupric crack are not applicable above 1 mg/L copper; this is a winemaking threshold, not a safety limit 6.

6 | Testing

Most copper results on this page come from ICP-MS, including cattle liver checked against a bovine liver reference material, serum checked against a whole-blood reference material, and dried brain tissue 5 8 4. Older and winery work used atomic absorption spectrometry: flame atomic absorption is the routine reference

method for grape must, and electrothermal atomic absorption measured exchangeable and total serum copper in the Wilson's disease model 6 7. The thyroid cancer study measured plasma copper by total reflection X-ray fluorescence, with an inter-assay variation below 15% 3.

A smartphone-read colorimetric polymer film quantified copper in grape must with a limit of detection of 0.08 ppm and a limit of quantification of 0.25 ppm, and its results did not differ significantly from flame atomic absorption 6. Such screening tools target winery process control and have not been shown to replace laboratory methods for other foods.

Two reporting issues recur. First, the fraction of copper measured matters: relative exchangeable copper, the loosely bound share of serum copper, separated rats with defective copper excretion from controls at every time point, while total serum copper did not 7. Second, units and basis vary widely, from µg/g wet weight in human organs to µmol/kg dry matter in cattle liver and brain tissue, so values cannot be compared without conversion 2 5 4.

7 | Microbiome effects

The cited evidence does not establish effects of dietary copper on the human gut microbiome. The only microbial evidence on this page concerns soil and plant-associated bacteria, whose effects on crop metal uptake can be either increases or decreases depending on organism, metal and plant 26.

8 | Vulnerable populations

Inherited defects of copper handling

Menkes disease and Wilson disease are inherited conditions of copper metabolism 1. In the rat model of Wilson's disease, ordinary dietary copper was enough to cause liver failure in every normally fed animal, while near-absence of dietary copper prevented it during the study 7. Relative exchangeable copper above 19.0% identified affected rats with 97.3% sensitivity and 100% specificity, and the authors propose it as a simple blood test for copper toxicosis caused by loss of ATP7B function 7.

Infants and young children

In Tokyo autopsy cases, liver copper was highest in the first years of life: the geometric mean was 15.21 µg/g in 6 infants under one year and 9.02 µg/g in 9 children aged 1 to 9, compared with 5.51 µg/g in 11 adults aged 70 and over 2. The study reports this as an age pattern in sudden-death cases and does not link it to diet.

Girls

One study reports urinary metal biomarkers and early-puberty associations in girls recruited across six Spanish hospitals during 2018 to 2022. The source keeps case and control summaries, detection frequencies and observational effect estimates separate. A single urine measurement and case-control sampling cannot establish exposure before puberty onset, causality, or a particular consumer-product source 27.

Older adults with neurodegenerative disease

Brain copper was lower in seven of nine regions in Parkinson's disease dementia, and blood copper did not differ significantly in a small Alzheimer's disease group, so the cited evidence points to copper depletion or redistribution in these conditions rather than copper overload 4 9.

9 | Mitigation

Diet and feed

Restricting dietary copper prevented liver failure during the 28-week study in rats lacking ATP7B function 7. For cattle, the authors recommend measuring liver copper stores in a representative share of the herd before supplementing, and reducing or stopping supplementation when stores are high; in their field experience it takes one to two years to bring liver copper from toxic to normal levels 5.

Crops and soils

A 2015 Rostov-region field experiment measured copper, zinc and lead in beetroot and potato grown on artificially metal-amended chernozem. Adding mineral fertilizer reduced several crop concentrations relative to the metal-only treatment, while yield responses differed between crops. Supports crop-specific agronomic mitigation and soil-to-crop transfer evidence. Artificially amended experimental crops are not a market-occurrence distribution. Paper limit comparisons remain secondary context 28.

A 2021 review examines vegetable-associated metal exposure assessment and microbial/agronomic risk-management approaches. Chinese and Russian case-study values are secondary reports; they remain traceable to the cited studies and are not counted as new independent occurrence samples. Supports exposure-method and remediation literature discovery. Bacterial effects can increase as well as decrease uptake depending on organism, metal and plant; the review does not establish a universal inoculant intervention. Secondary model outputs are not contemporary health or certification thresholds 26.

Sludge and water treatment

Column washing of Bangalore-area industrial sludge removed substantially more metals with hydrochloric acid plus EDTA than with distilled water. This is a remediation experiment relevant to sludge contamination pathways, with no measurements in food or a demonstrated safe land-application endpoint. Supports laboratory washing and contaminant-transport comparisons. Metal-rich leachate still requires management; the study does not establish agricultural reuse or field-scale safety 29.

In synthetic copper(II) solution initially measured at 105 ppm, a 2021 hydrogel thesis reports 103.7 ± 1.9 mg/g dry gel operational removal for the foamed and foam-stabilized material after 24 hours (three replicates; Results 2.4.7). In a mixed solution labeled 35 ppm copper, 42 ppm cadmium and 35 ppm nickel, the corresponding copper bar is approximately 30 mg/g. These quantities use the change in aqueous metal mass after recovery of the swollen gel, including the change in liquid volume. They do not directly establish polymer-bound copper or treated-water safety 30.

Food processing

The cited evidence does not establish a processing step that lowers copper in finished foods. In winemaking, the treatments used against cupric crack are described as not applicable above 1 mg/L copper, which is why wineries measure copper in must 6.

10 | Open questions

- No cited paper reports copper concentrations in a total diet, a national food survey or retail foods at scale, so dietary copper intake for any population is not established here.

- Copper in finished wine, retail liver and other organ meats has not been measured by the cited evidence; only grape must and cull-cattle liver categories are available.
- Regulatory limits: the cited evidence gives animal-feed and clinical reference values but no human food, supplement or drinking-water limit for copper.
- Microbiome effects: no cited paper examines dietary copper and the human gut microbiome.
- Drinking water: the only water measurement is river water in the Ganga basin; no tap or bottled water data are cited.
- Human toxicity thresholds: the cited toxicology rests on a textbook chapter and a rat model of Wilson's disease; no human dose-response data for copper excess are cited.
- Whether altered plasma or brain copper in thyroid cancer and dementia reflects intake, inflammation or disease processes is not resolved by the cited case-control studies.
- Mitigation for foods: no cited study tests processing or cooking steps that reduce copper in food.

11 | Frequently asked questions

Is copper actually necessary for the body, or is it just a contaminant?

Copper is an essential metal, not only a contaminant. It is required by enzymes including cytochrome c oxidase, lysyl oxidase, and Cu/Zn superoxide dismutase Ufelle & Barchowsky 2021. The concern arises from excess rather than from copper being present at all.

What happens if you get too much copper?

Excess copper can produce gastrointestinal and hepatic (liver) toxicity Ufelle & Barchowsky 2021. The page frames this as an effect of excess copper, in contrast to copper's essential role at normal levels.

Are there genetic conditions that affect how the body handles copper?

Yes. Inherited copper-metabolism disorders include Menkes disease and Wilson disease Ufelle & Barchowsky 2021. These are disorders of copper metabolism rather than dietary-exposure effects.

12 | What remains uncertain

The copper evidence cited here is broad but shallow. Human values come from small clinical or post-mortem case-control studies and one 1970s Japanese autopsy series, each measuring a different fraction (plasma, serum, blood, organ tissue) with different units and bases. None measures intake, so none can say how much dietary copper is too much or too little for people.

Food evidence is limited to categories of cattle liver at slaughter, grape must before fermentation, and vegetables or botanicals sampled in contaminated settings. These show that copper can be high in some foods and production chains, but not how often, and not in the forms people buy. The toxicology rests on a textbook summary and one rat model of Wilson's disease, which shows the importance of impaired copper excretion but does not give a human threshold for the general population.

References

[1] Toxic Effects of Metals (Chapter 23), in Casarett & Doull's Essentials of Toxicology, Fourth Edition
Ufelle AC and Barchowsky A · Casarett & Doull's Essentials of Toxicology, Fourth Edition. McGraw Hill Education · 2021 · www.-mhprofessional.com
TEXTBOOK

[2] Interrelationships among Zinc, Copper, Lead, and Cadmium in Food, Feces, and Organs of Humans
Tsuchiya K and Iwao S · Environmental Health Perspectives 25: 119-124 · 1978 · doi.org/10.1289/ehp.7825119
PEER-REVIEWED

[3] Copper Isotopes and Copper to Zinc Ratio as Possible Biomarkers for Thyroid Cancer
Kazi Tani LS, Gourlan AT, Dennouni-Medjati N, Telouk P, Dali-Sahi M, Harek Y, et al. · Frontiers in Medicine 8: 698167 · 2021 · doi.org/10.3389/fmed.2021.698167
PEER-REVIEWED

[4] Widespread Decreases in Cerebral Copper Are Common to Parkinson's Disease Dementia and Alzheimer's Disease Dementia
Scholefield M, Church SJ, Xu J, Patassini S, Roncaroli F, Hooper NM, et al. · Frontiers in Aging Neuroscience 13: 641222 · 2021 · doi.org/10.3389/fnagi.2021.641222
PEER-REVIEWED

[5] Liver copper concentrations in cull cattle in the UK: are cattle being copper loaded?
Kendall NR, Holmes-Pavord HR, Bone PA, Ander EL, and Young SD · Veterinary Record, 14 November 2015 (volume and pages not printed on the article PDF) · 2015 · doi.org/10.1136/vr.103078
PEER-REVIEWED

[6] Democratization of Copper Analysis in Grape Must Following a Polymer-Based Lab-on-a-Chip Approach
Guirado-Moreno JC, Carreira-Barral I, Ibeas S, García JM, Granès D, Marchet N, et al. · ACS Applied Materials & Interfaces 15: 16055-16062 · 2023 · doi.org/10.1021/acsami.3c00395
PEER-REVIEWED

[7] Evolution of Exchangeable Copper and Relative Exchangeable Copper through the Course of Wilson's Disease in the Long Evans Cinnamon Rat
Schmitt F, Podevin G, Poupon J, Roux J, Legras P, Trocello JM, et al. · PLoS ONE 8(12): e82323 · 2013 · doi.org/10.1371/journal.pone.0082323
PEER-REVIEWED

[8] Selenium, Zinc, and Copper Status in Euthyroid Nodular Goiter: A Cross-Sectional Study
Turan E and Turksoy VA · International Journal of Preventive Medicine 12: 46 · 2021 · doi.org/10.4103/ijpvm.ijpvm_337_19
PEER-REVIEWED

[9] Association of trace elements Aluminum, Copper and Zinc in blood of Alzheimer's disease
Anwar M · Alzheimer's & Dementia 21(Suppl. 6): e107018 · 2025 · doi.org/10.1002/alz70860_107018
CONFERENCE

[10] Oxidative stress in stingless bees exposed to pesticides and heavy metals: a systematic review
Laísa Prestes and Denise Cargnelutti · Scientific Electronic Archives 19(3):1-9 · 2026 · doi.org/10.36560/19320262200
PEER-REVIEWED

[11] Heavy Metal Contamination of Animal Feed in Texas
Susie Y. Dai, Ben Jones, Kyung-Min Lee, Wei Li, Lynn Post, and Timothy J. Herrman · Journal of Regulatory Science4(1):21–32 · 2016 · doi.org/10.21423/jrs-v04n01p021
PEER-REVIEWED

[12] LABORATORY SCALE ELECTROKINETIC REMEDIATION OF HEXAVALENT CHROMIUM FROM CONTAMINATED SOIL
M. Khalid, N. Ahmed, and R. M. Qureshi · The Nucleus 45(1–2):55–61 · 2008 · doi.org/10.71330/nucleus.45.01-2.998
PEER-REVIEWED

[13] Spatial contamination and health risks of heavy metal(loid)s in surface soils from a petrochemical complex in the north-eastern region of Algeria
Hayat Boudia, Laurent Vassalo, Mohammed Hadjel, Pascale Prudent, and Jean-Luc Boudenne · International Journal of Environmental Science and Technology 16:4707–4718; HAL author-manuscript version read · 2019 · doi.org/10.1007/s13762-018-02195-1
PEER-REVIEWED

[14] Bioaccumulative and conchological assessment of heavy metal transfer in a soil-plant-snail food chain
Dragos V Nica, Marian Bura, Iosif Gergen, Monica Harmanescu, and Despina-Maria Bordean · Chemistry Central Journal 6:55 · 2012 · doi.org/10.1186/1752-153X-6-55
PEER-REVIEWED

[15] Bioaccumulation and potential sources of heavy metal contamination in fish species in River Ganga basin: Possible human health risks evaluation
Pradip Kumar Maurya, D. S. Malik, Krishna Kumar Yadav, Amit Kumar, Sandeep Kumar, and Hesam Kamyab · Toxicology Reports 6:472–481 · 2019 · doi.org/10.1016/j.toxrep.2019.05.012
PEER-REVIEWED

[16] Soil–water–crop pathways of heavy metal contamination and human health risks in intensive smallholder farms of the Nahavand Plain, Iran
Saeed Sharafi, Maryam Sharafi, and Maryam Lorvand · Scientific Reports 16:9947 · 2026 · doi.org/10.1038/s41598-026-38637-x
PEER-REVIEWED

[17] Wastewater Irrigation and Accumulation of Heavy Metals in Vegetable Crops (Broccoli and Cauliflower)
Bayan Rashid Rahim · Tikrit Journal for Agricultural Sciences 23(2):162–170 · 2023 · doi.org/10.25130/tjas.23.2.13
PEER-REVIEWED

[18] Effects of sewage water irrigation on heavy metals accumulation in vegetables in peri-urban areas of Faisalabad, Pakistan
Muhammad Abubakar, Basit Haider, Hadeeqa Arshad, Tufail Shah, Ameer Khan, Hummera Nawaz, et al. · Agricultural Research Reports 3(1):46–57 · 2025 · doi.org/10.54219/arr.03.1.2025.418
PEER-REVIEWED

[19] Assessment of the Level of Heavy Metals in Irrigation Water, Farm Soil, and Vegetables Grown in Gobbiya Dam, Bogoro Local Government Area Bauchi State, Nigeria
John Joseph, Toma Buba, Jalo Enoch, and Ayuba Kaluri · Journal of Energy Technology and Environment 7(4):79–92 · 2025 · doi.org/10.37933/jete/7.4.2025.2568
PEER-REVIEWED

[20] Analysis of a Wild Leafy Vegetable (Premna latifolia Roxb.) Samples for Essential Trace Elements using ICP - MS Technique
G. Narayana Murthy and Balarama Swamy Yadav Padala · International Journal of Scientific Engineering and Research 12(2):1–4 · 2024 · doi.org/10.70729/se24205180530
PEER-REVIEWED

[21] Bioaccessibility of Heavy Metals in Raw and Processed Alternanthera sessilis and Centella asiatica: An In vitro Study
Thilini Kananke, Jagath Wansapala, and Anil Gunarathne · Nature Environment and Pollution Technology25(1):D1830 · 2026 · doi.org/10.46488/nept.2026.v25i01.d1830
PEER-REVIEWED

[22] HEAVY METALS ACCUMULATION IN SOIL AND CELERY ROOT (APIUM GRAVEOLENS L.) HARVESTED FROM THE POLLUTED AREAS IN SIBIU COUNTY, CENTRAL ROMANIA
Bogdan Ștefan Oprea, Nicoleta Olimpia Vrînceanu, Dumitru-Marian Motelică, Georgiana Iuliana Plopeanu, Vera Carabulea, and Mihaela Costea · Annals of the University of Craiova—Agriculture,Montanology,Cadastre52(1):422–429 · 2022 · doi.org/10.52846/aamc.v52i1.1370
PEER-REVIEWED

[23] Application of principal component analysis in the pollution assessment with heavy metals of vegetable food chain in the old mining areas
Iosif Gergen and Monica Harmanescu · Chemistry Central Journal6:156 · 2012 · doi.org/10.1186/1752-153x-6-156
PEER-REVIEWED

[24] Study of Peculiarities of Accumulation of Heavy Metals and Arsenic in Medicinal Plant Raw Materials of Synanthropic Flora of Voronezh Region
Nina Alekseevna Dyakova · Khimiya Rastitel'nogo Syr'ya 2:163–170 · 2023 · doi.org/10.14258/jcprm.20230211725
PEER-REVIEWED

[25] Levels of heavy metals concentrations in chocolates from Bwari market Abuja FCT, Nigeria
Emmanuel Joy Enogbe and Agbaghare Daniel Enajeme · International Journal of Adulteration9:e2ijad3057 · 2025 · doi.org/10.54905/disssi.v9i10.e2ijad3057
PEER-REVIEWED

[26] Assessment of the Risk of Heavy Metals Accumulation in Vegetable Crops
Vladimir N. Bashkin and Rosa A. Galiulina · Issues of Risk Analysis 18(4): 48-65 · 2021 · doi.org/10.32686/1812-5220-2021-18-4-48-65
PEER-REVIEWED

[27] Association of exposure to synthetic phenols and metal(loid)s with early puberty in Spanish girls: a multicentric case–control study
Olivas-Martinez A, Escribano A, Riaño-Galán I, Torrebias M, Olmedo P, Gil F, et al. · European Journal of Pediatrics 185:295 · 2026 · doi.org/10.1007/s00431-026-06919-1
PEER-REVIEWED

[28] Yield Assessment of Beetroot and Potato, Cultivated on Ordinary Chernozem Contaminated with Heavy Metals
N. V. Gromakova · Vegetable Crops of Russia 5(38):74–75 · 2017 · doi.org/10.18619/2072-9146-2017-5-74-75
PEER-REVIEWED

[29] Removal of Heavy Metals from Industrial Sludge Using Soil Washing Technique
J. Sumalatha, B. P. Naveen, and R. K. Malik · Asian Journal of Water, Environment and Pollution 16(3):83–89 · 2019 · doi.org/10.3233/ajw190036
PEER-REVIEWED

[30] The use of foaming agents and foam stabilizers to improve heavy metal removal properties of acrylic acid/acrylamide hydrogels for use in wastewater remediation
Ann Pille · MSc thesis, Bioresource Engineering, McGill University, Macdonald Campus; December2021 · 2021 · mcgill.scholaris.ca
THESIS

STATUS AND LICENCE

Editorially reviewed in-house; no external peer review has been completed on this reference. Published as an institutional technical report with its review state tracked on the article page. Released under CC BY 4.0.

COMPETING INTERESTS

The Heavy Metal Index reports what the peer-reviewed and regulatory literature supports. It is operated separately from any certification program, does not evaluate or endorse brands, and does not use certification thresholds as evidence for the statements made here.

DATA AVAILABILITY

Every source behind this reference is listed with its own source record at https://heavymetalindex.com/metals/copper#sources.

PUBLICATION HISTORY

This revision 2026-11-03. The full dated record is maintained at https://heavymetalindex.com/metals/copper.